ROBOTICS

CHAPTER 1: INTRODUCTION TO INDUSTRIAL ROBOTICS

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1.1. INTRODUCTION TO INDUSTRIAL ROBOT

■ Definition

- Robotic Institute of America(RIA): Robot is a re-programmable multi-functional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks, which also acquire information from the environment and move intelligently in response

- The term “Robot” comes from a Czech word, *robota*, meaning "forced labor";the word 'robot' was first used to denote a fictional humanoid in a 1920 play *R.U.R. (Rossumovi Univerzální Roboti - Rossum's Universal Robots)* by the Czech writer, Karel Čapek but it was Karel's brother Josef Čapek who was the word's true inventor.

- In general, robotics is commonly defined as the science studying the intelligent connection between perception and action.

➔ Therefore, it can be recognized that robotics is an interdisciplinary subject concerning the cultural areas of mechanics, control, computers, and electronics.

1.1. INTRODUCTION TO INDUSTRIAL ROBOT

History of Industrial Robot

- The first digitally operated and programmable robot was invented by George Devol in 1954 and was ultimately called the Unimate.
- Devol sold the first Unimate to General Motors in 1960, and it was installed in 1961 in a plant in Trenton, New Jersey to lift hot pieces of metal from a die casting machine and stack them.

1.1. INTRODUCTION TO INDUSTRIAL ROBOT

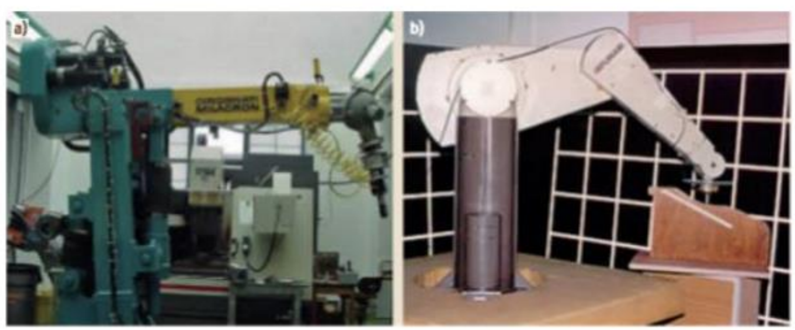
History of Industrial Robot

- The first palletizing robot was introduced in 1963 by the Fuji Yusoki Kogyo Company.
- In 1973, a robot with six electromechanically driven axes was patented by KUKA robotics in Germany.
- The programmable universal manipulation arm was invented by Victor Scheinman in 1976, and the design was sold to Unimation.

ASEA IRB-6 (1973) first robot all-electric-drives

Hirata AR-300 (1978) first SCARA robot

Cincinnati Milacron T3 (1974) first micro-computer controlled robot



Unimation PUMA 560 (1979) 6R with human-like dexterity

1.1. INTRODUCTION TO INDUSTRIAL ROBOT

History of Industrial Robot: Robots – a 50-year journey

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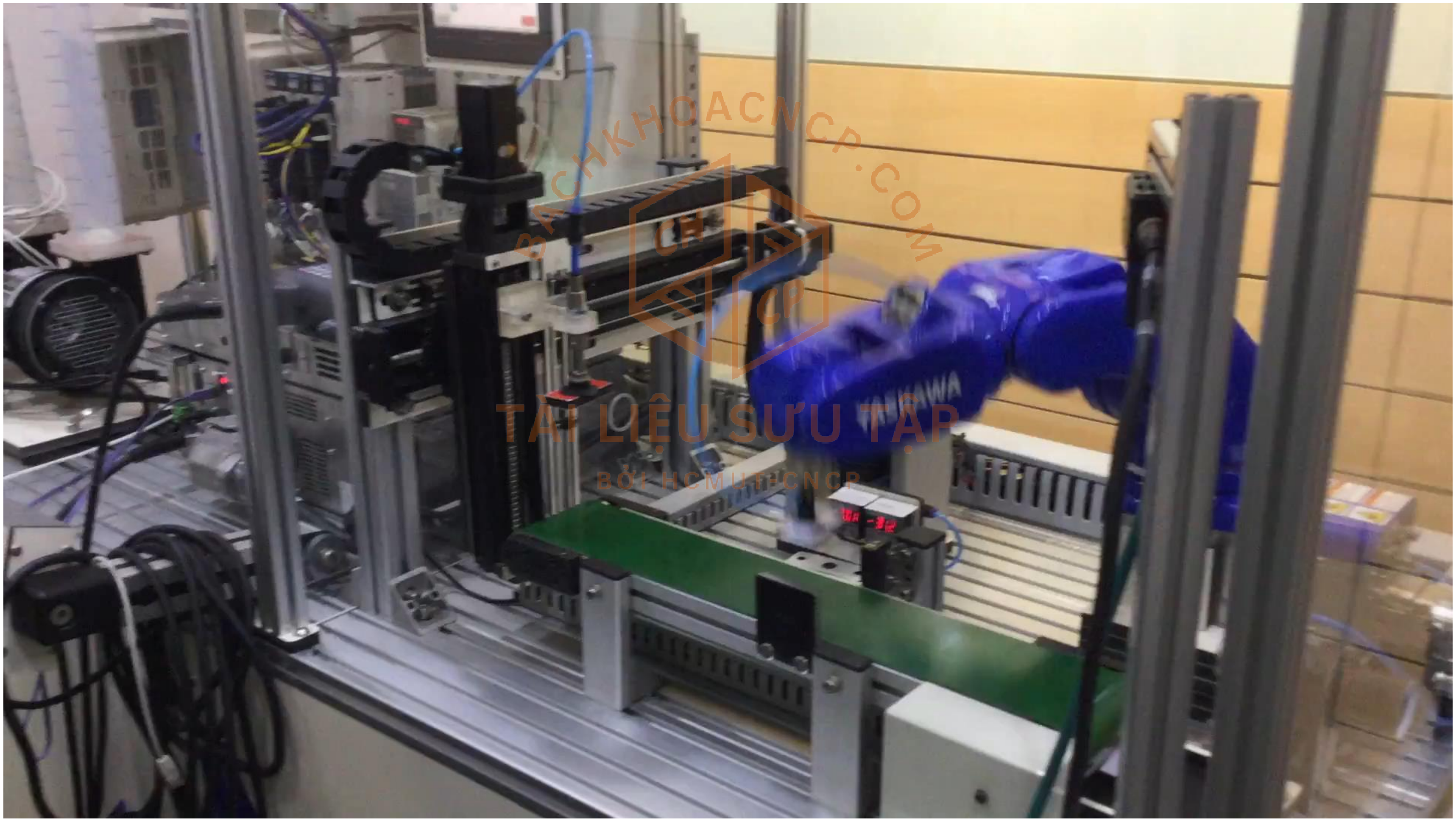


1.1. INTRODUCTION TO INDUSTRIAL ROBOT

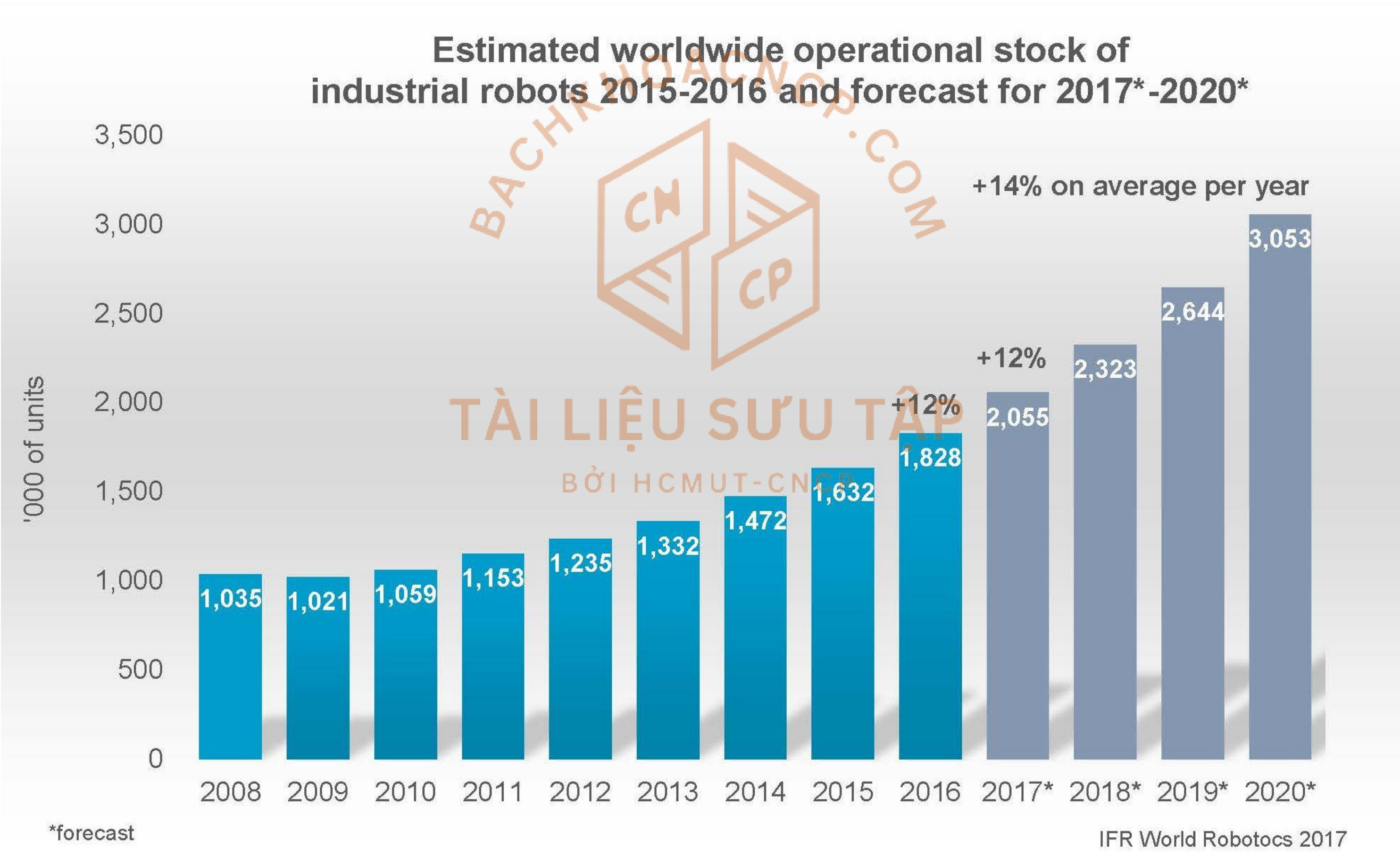
■ World Robotics 2017

- Robotics market value in 2016: $13.1 billion (+18% over 2015); robot systems: $40 billion.
- Total worldwide stock at end 2016: 1.8 million units of operational industrial robots (+12%).
- Highest ever robot sales worldwide in 2016 (~295K, +16%), for the fourth year in a row.
- China expanded further as the largest market since 2013, now with a 30% share (+3%).
- 75% of sales goes to 5 countries: first is China (87K, close to Europe + Americas = 97K), then Korea (41K, +10%/year average since 2011), Japan (38K, +10%), USA (31K, +14%), and Germany (20K, steady); Italy (6.7K, steady) is the 2nd market in Europe (7th worldwide).
- Main industrial drivers: automotive (35% of new robots, with moderate rate increase) and electrical/electronics (31%, catching up very fast; now first in Asia), followed by metal and machinery, rubber and plastics, food industry, ...

A continued accelerated growth!

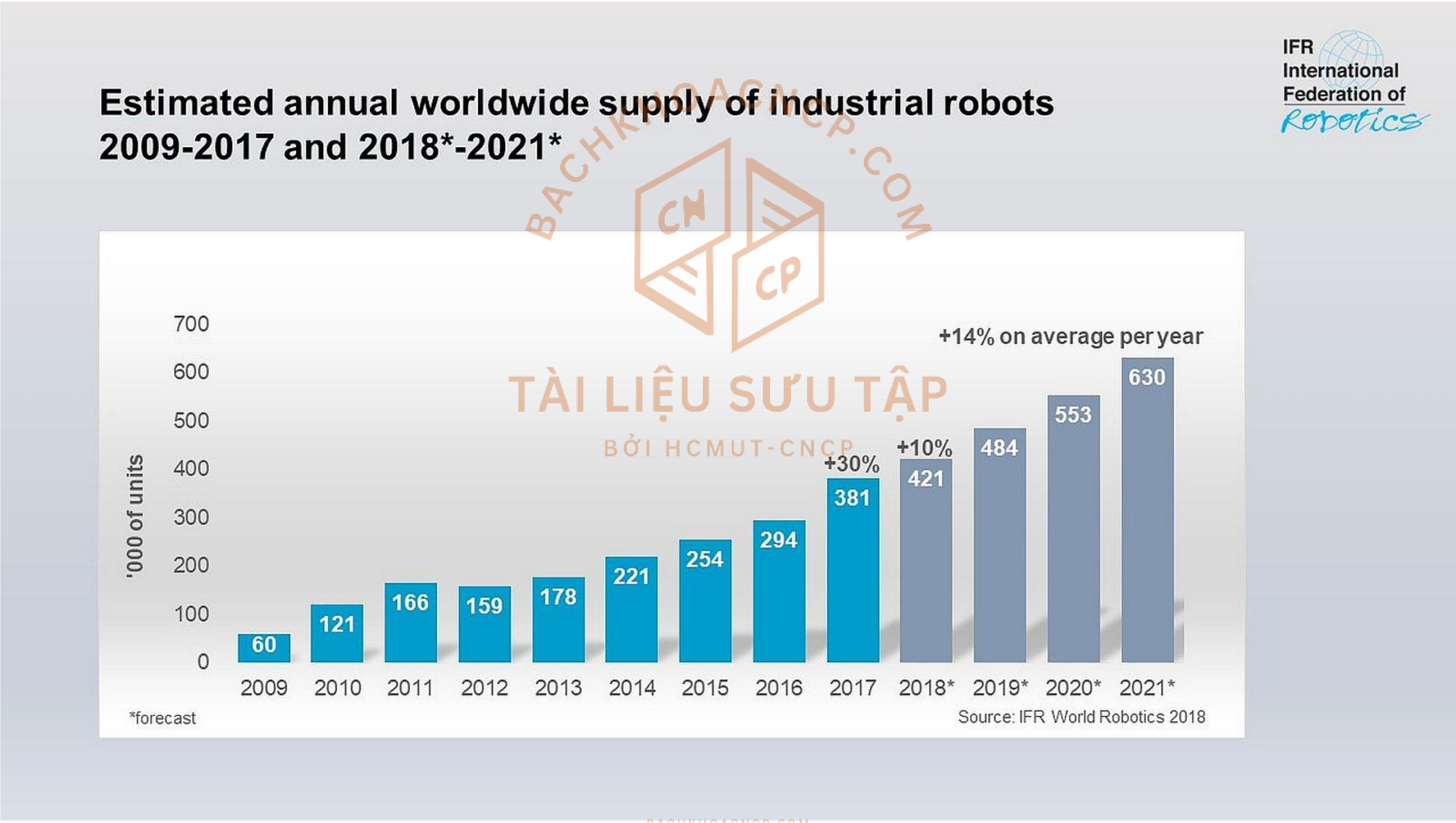
1.1. INTRODUCTION TO INDUSTRIAL ROBOT

■ Industrial robots in operation worldwide



1.1. INTRODUCTION TO INDUSTRIAL ROBOT

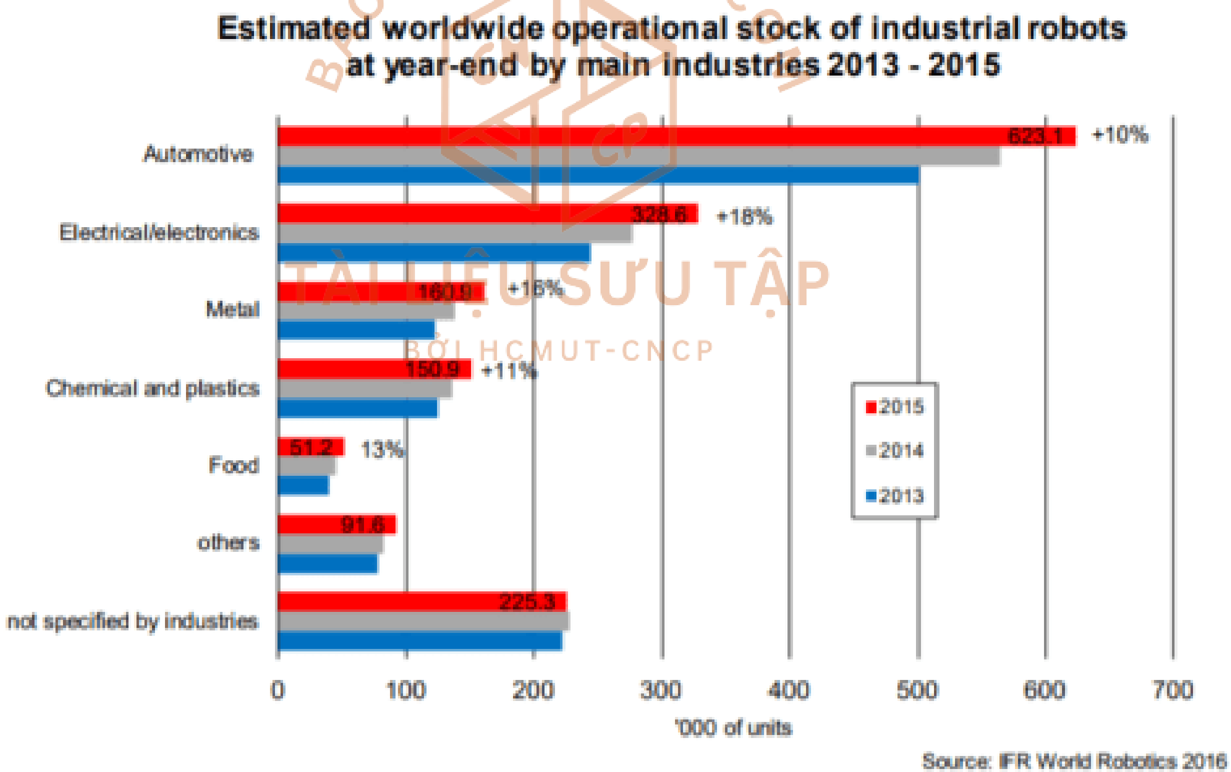
New Industrial robots worldwide



1.1. INTRODUCTION TO INDUSTRIAL ROBOT

Robots in industrial sectors

Almost 70% in three main industries



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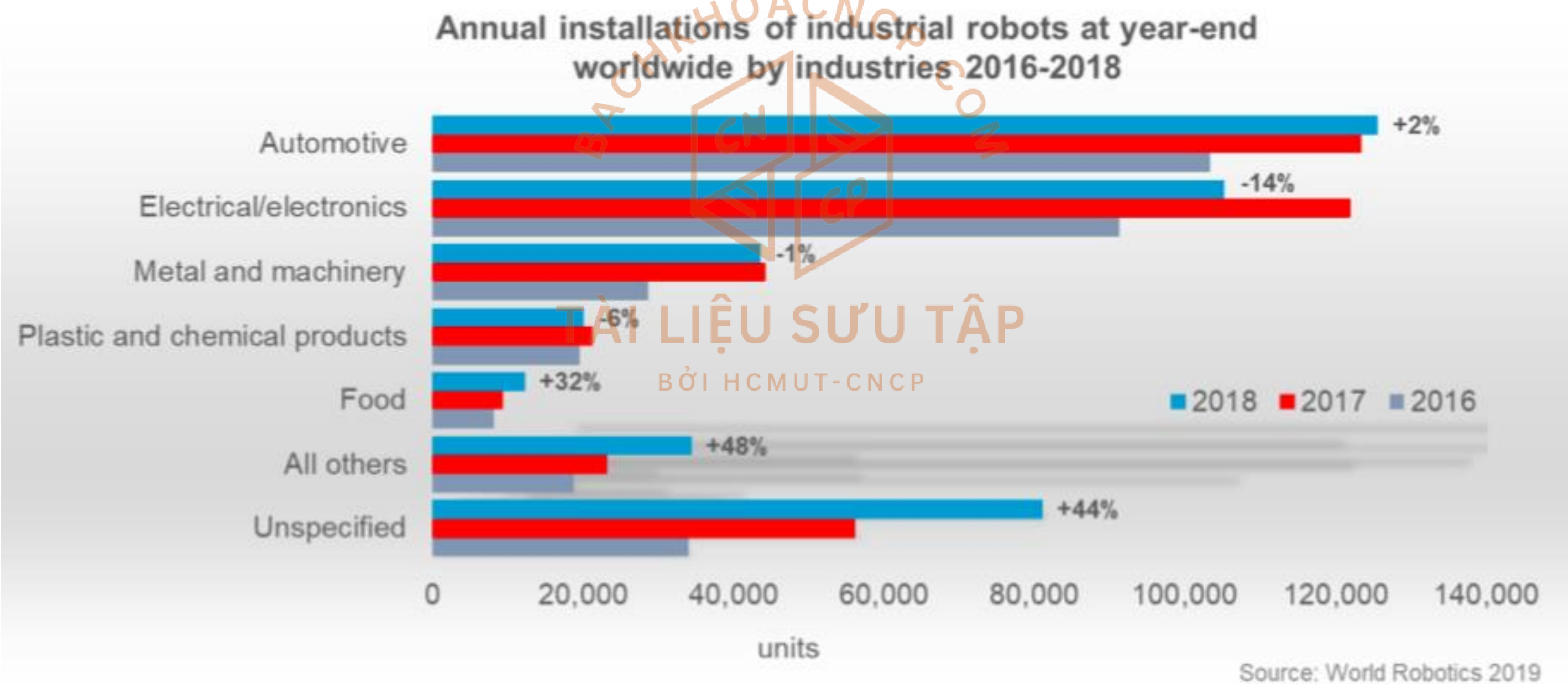
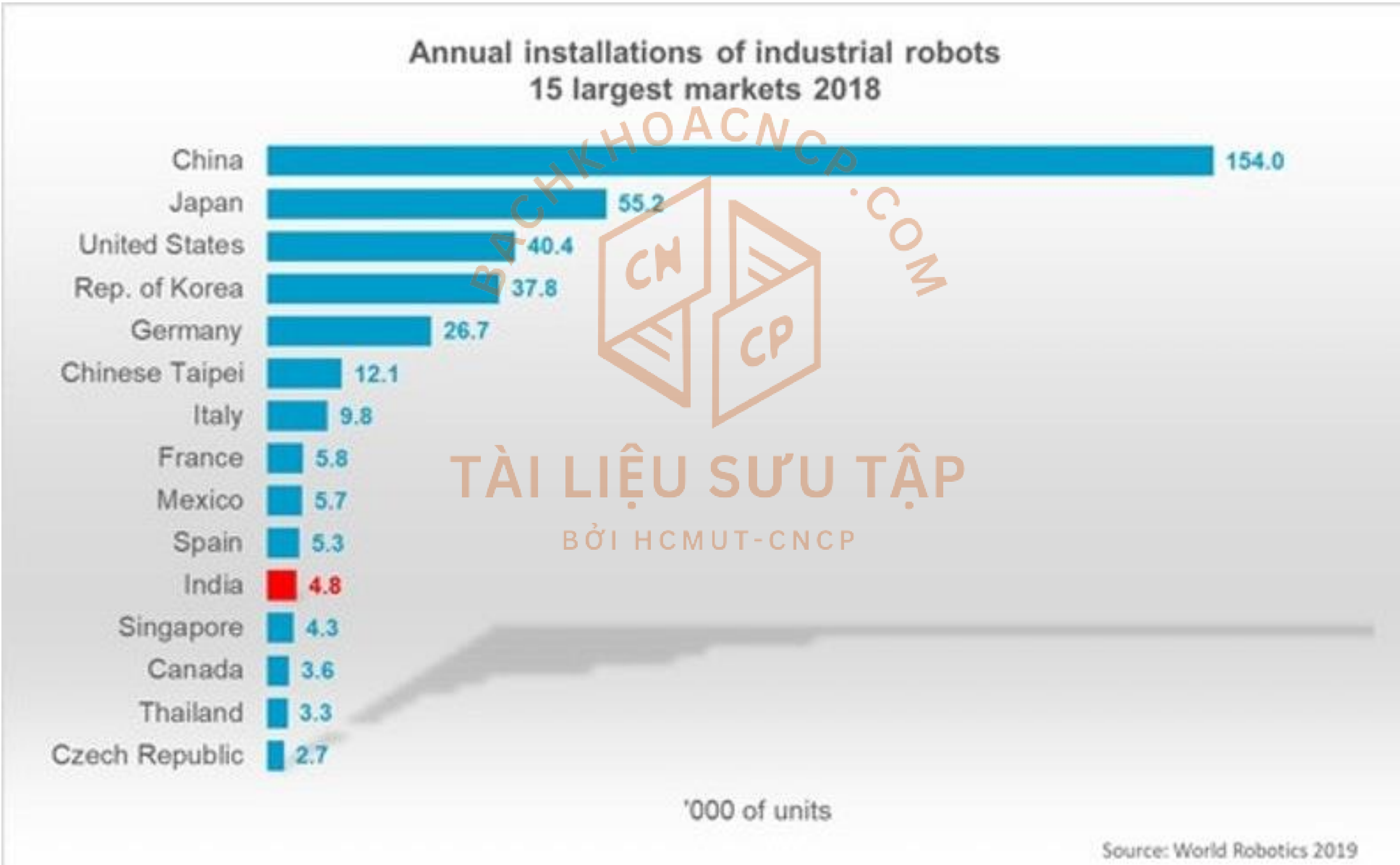
New Robots in industrial sectors



1.1. INTRODUCTION TO INDUSTRIAL ROBOT

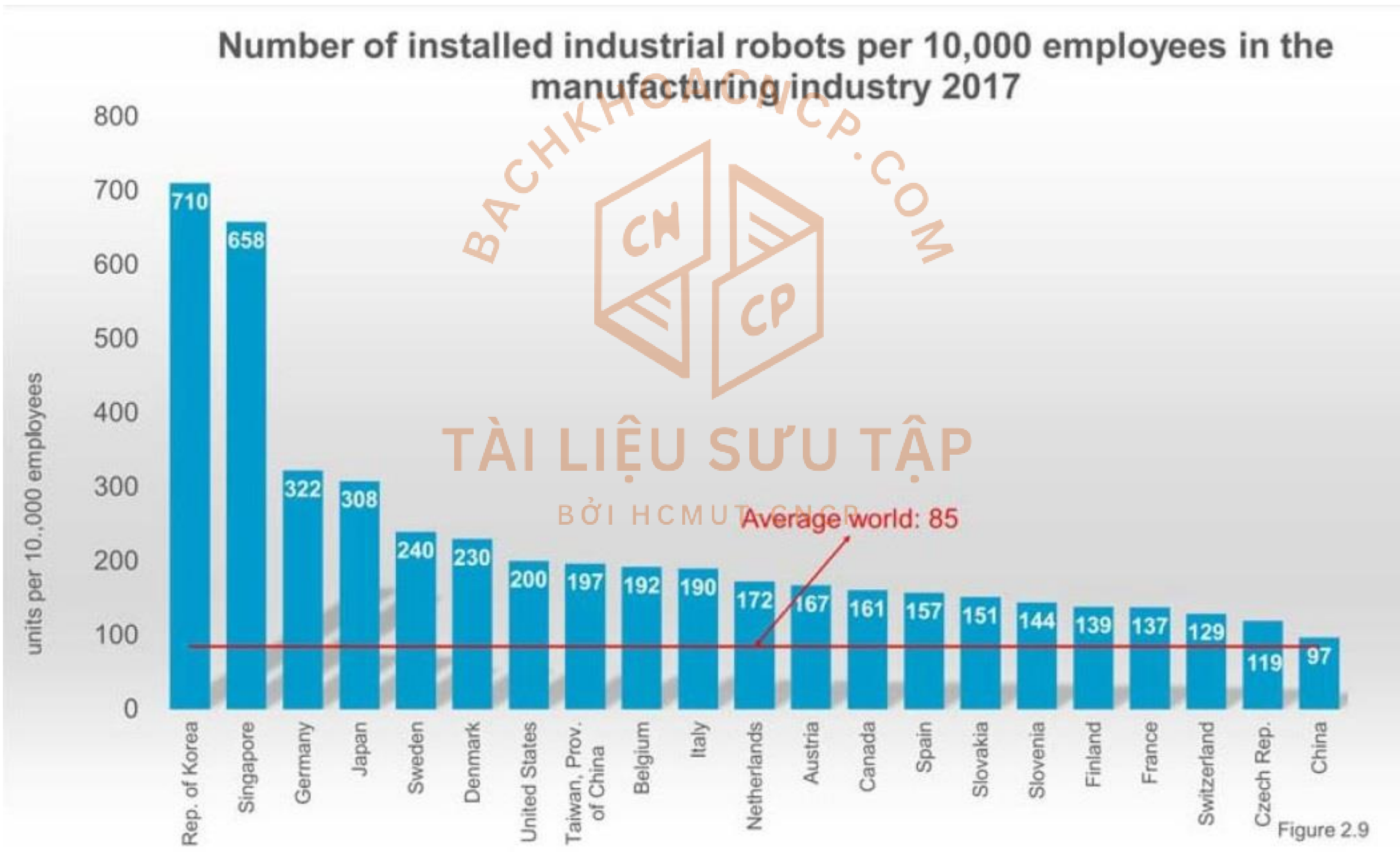
New installations in top markets (countries)



in 2018: top 5 markets account for 75% of total supply

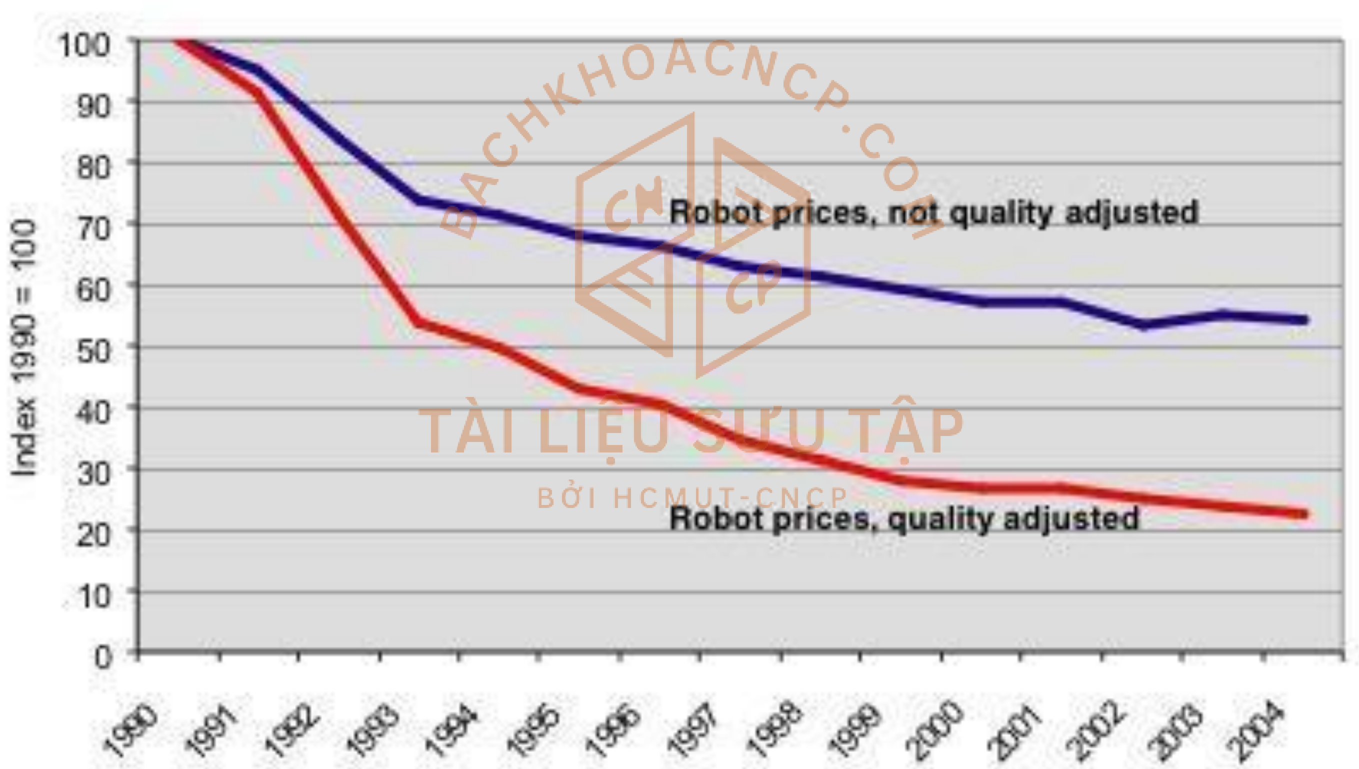
1.1. INTRODUCTION TO INDUSTRIAL ROBOT

Density of Robots



1.1. INTRODUCTION TO INDUSTRIAL ROBOT

Trend in Robot prices

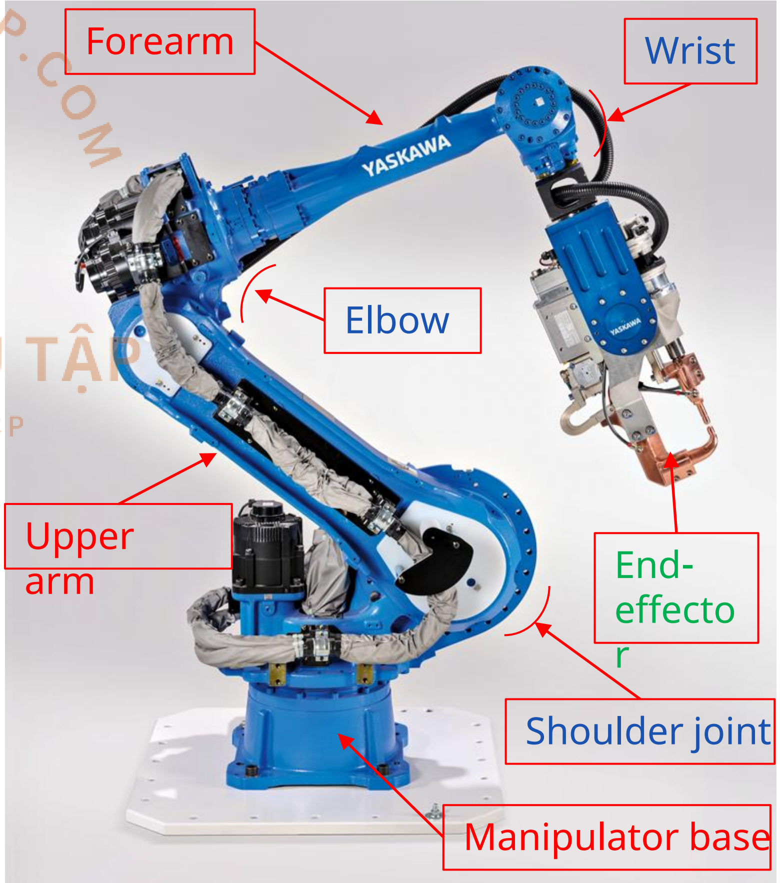


1.2. ROBOT MECHANICAL STRUCTURE

- Robots can be classified as those with a fixed base, robot manipulators, and those with a mobile base, mobile robots

Robot Manipulators

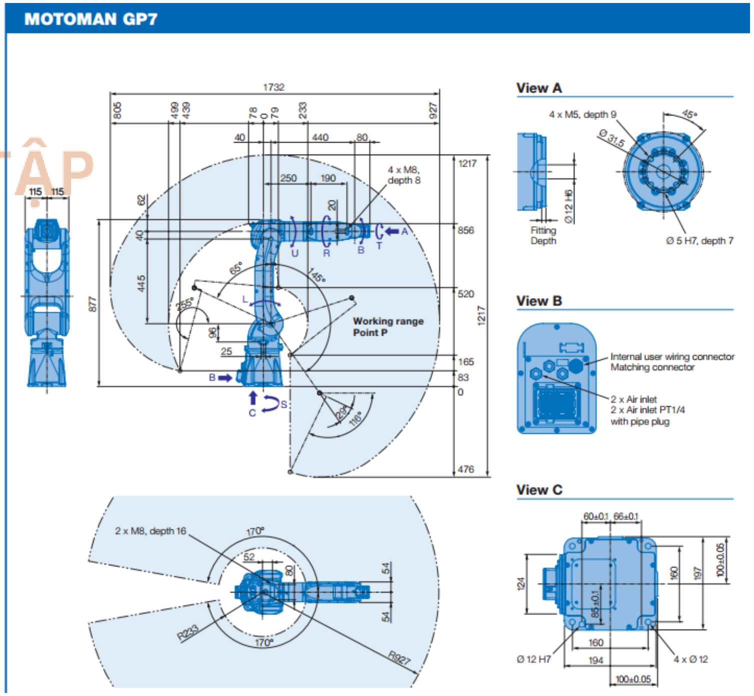
- The mechanical structure of a robot manipulator consists of a sequence of rigid bodies (links) interconnected by means of articulations (joints)
- A manipulator is characterized by an arm that ensures mobility, a wrist that confers dexterity, and an end-effector that performs the task required of the robot.



1.2. ROBOT MECHANICAL STRUCTURE

Robot Manipulators

- The articulation between two consecutive links can be realized by means of either a prismatic or a revolute joint.
- In an open kinematic chain, each prismatic or revolute joint provides the structure with a single degree of freedom (DOF)
- The workspace represents that portion of the environment the manipulator's end-effector can access. Its shape and volume depend on the manipulator structure as well as on the presence of mechanical joint limits.

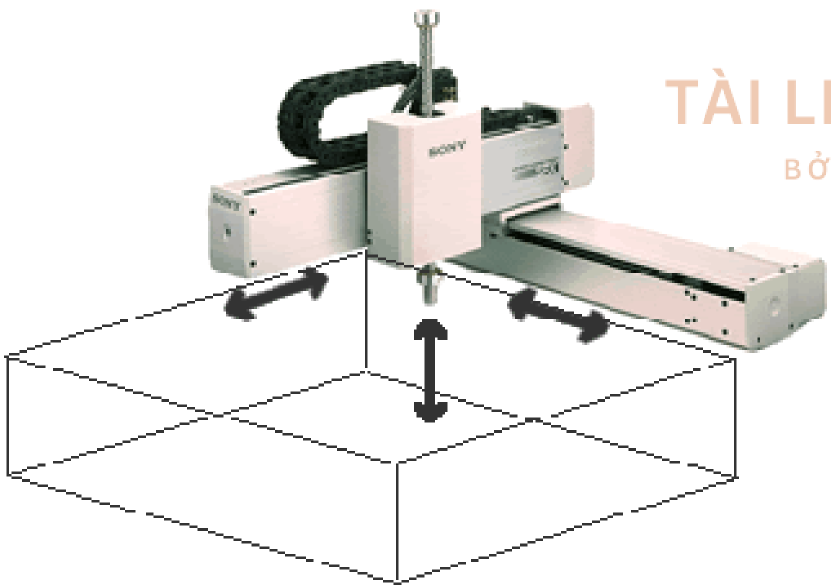


1.2. ROBOT MECHANICAL STRUCTURE

Robot Manipulators

- The type and sequence of the arm's DOFs, starting from the base joint, allows a classification of manipulators as Cartesian, Cylindrical, Spherical, SCARA, and Anthropomorphic.

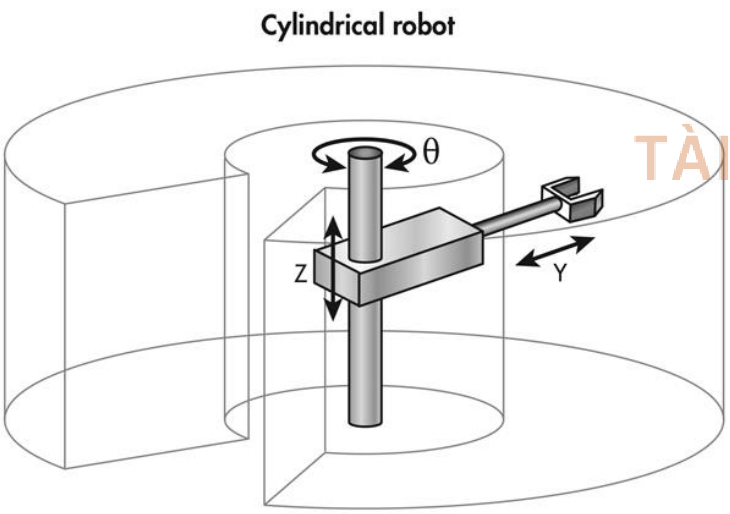
- Cartesian geometry (PPP) is realized by three prismatic joints whose axes typically are mutually orthogonal. In view of the simple geometry, each DOF corresponds to a Cartesian space variable and thus it is natural to perform straight motions in space.

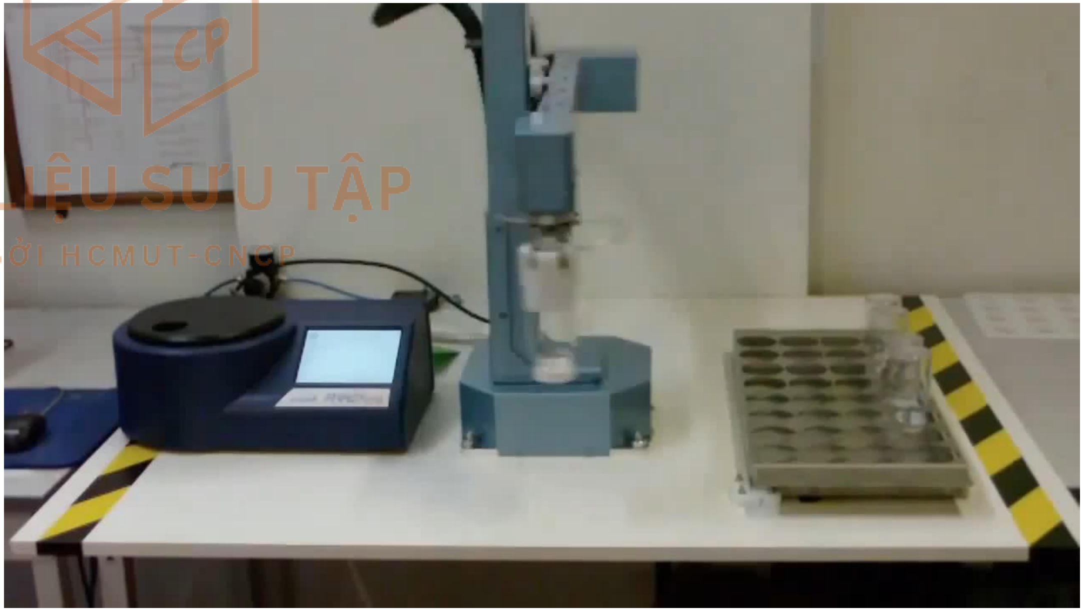


1.2. ROBOT MECHANICAL STRUCTURE

Robot Manipulators

❖ Cylindrical geometry (RPP) differs from Cartesian in that the first prismatic joint is replaced with a revolute joint. If the task is described in cylindrical coordinates, in this case each DOF also corresponds to a Cartesian space variable.

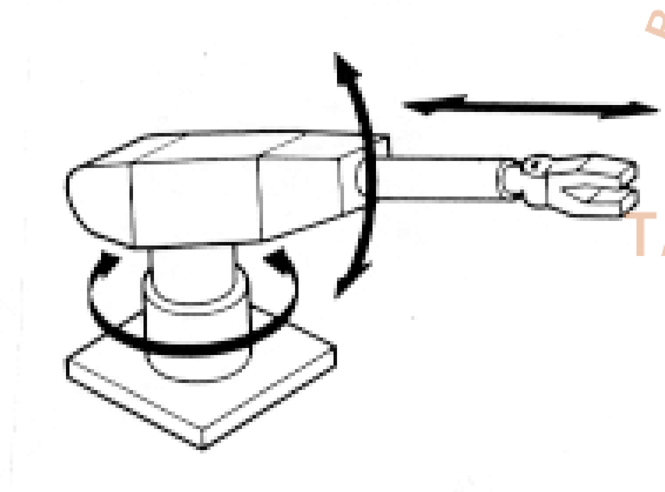


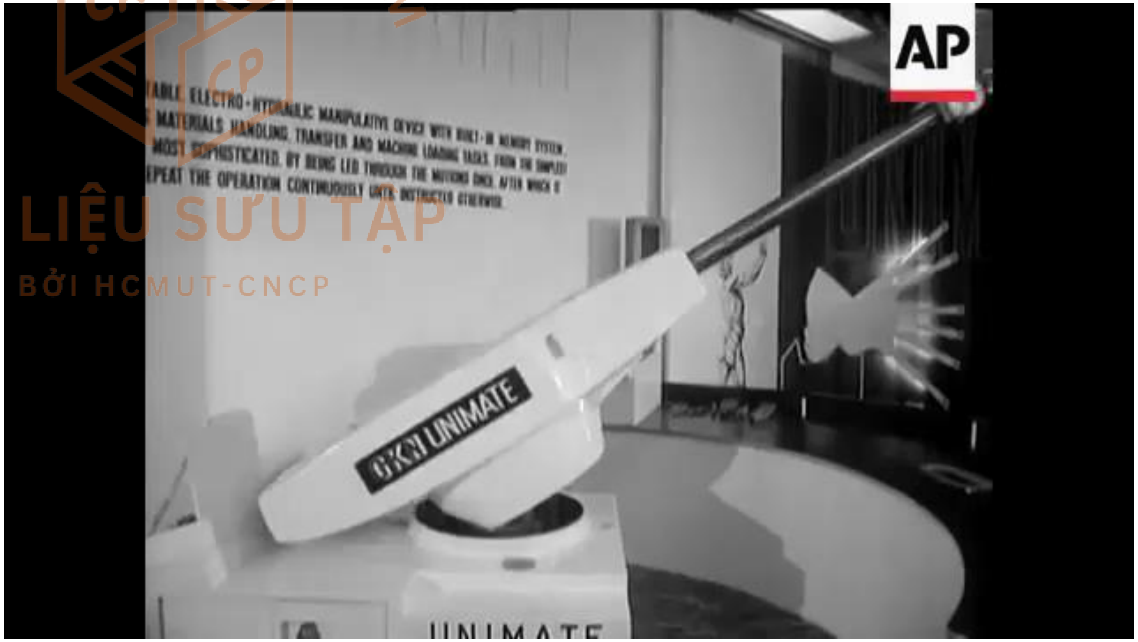


1.2. ROBOT MECHANICAL STRUCTURE

Robot Manipulators

- Spherical geometry (RRP) differs from cylindrical in that the second prismatic joint is replaced with a revolute joint. Each DOF corresponds to a Cartesian space variable provided that the task is described in spherical coordinates.

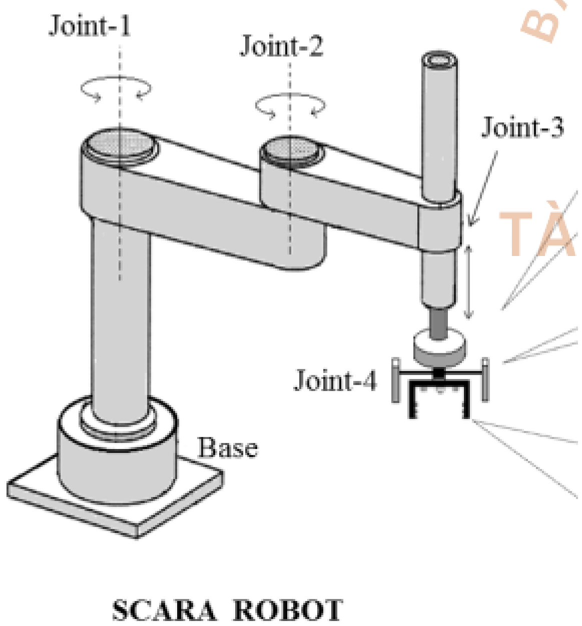


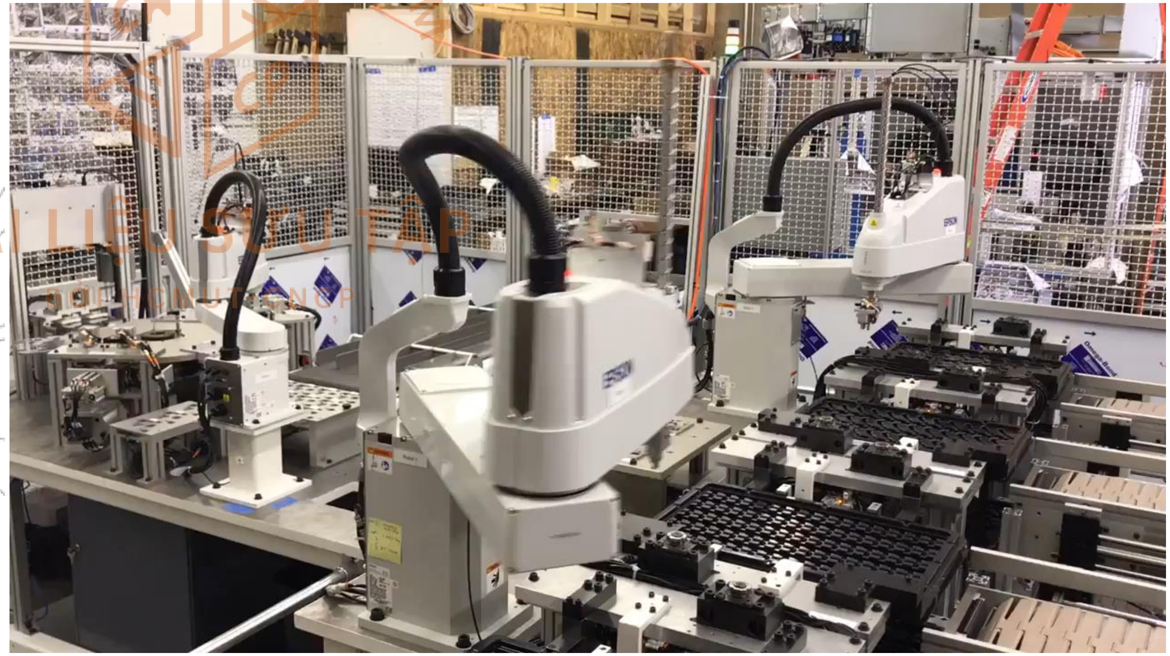


1.2. ROBOT MECHANICAL STRUCTURE

Robot Manipulators

- SCARA(Selective Compliance Assembly Robot Arm) geometry (RRP) that can be realized by disposing two revolute joints and one prismatic joint in such a way that all the axes of motion are parallel

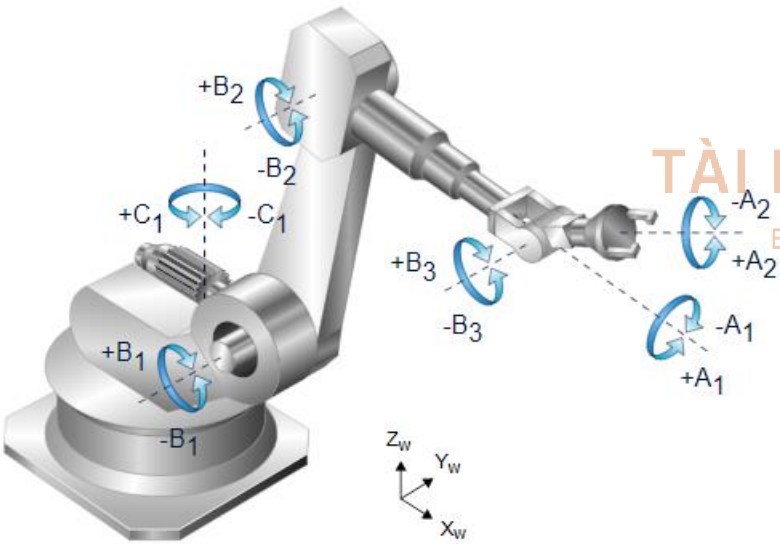




1.2. ROBOT MECHANICAL STRUCTURE

Robot Manipulators

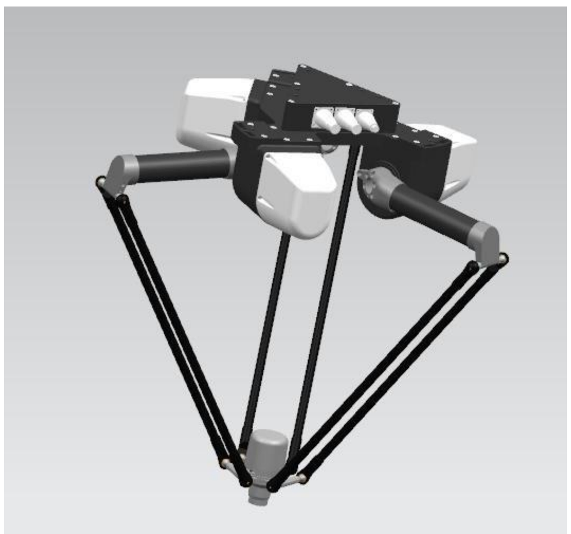
- Anthropomorphic geometry- Articulated geometry (RRR) is realized by three revolute joints; the revolute axis of the first joint is orthogonal to the axes of the other two which are parallel. By virtue of its similarity with the human arm, the second joint is called the shoulder joint and the third joint the elbow joint since it connects the "arm" with the "forearm."



1.2. ROBOT MECHANICAL STRUCTURE

Robot Manipulators

- A closed-chain geometry is parallel geometry which has multiple kinematic chains connecting the base to the end-effector. The fundamental advantage is seen in the high structural stiffness, with respect to open-chain manipulators, and thus the possibility to achieve high operational speeds; the drawback is that of having a reduced workspace.



Delta Robot

1.2. ROBOT MECHANICAL STRUCTURE

Robot Manipulators

YASKAWA MOTOMAN GP7

GP7 Basic Specifications

Item	Model	MOTOMAN-GP7
Application		Handling
Structure		Vertically Articulated
Degree of freedom		6
Payload	Wrist part	7 kg
	U-arm[2)]	1 kg
Repeatability[3)]		±0.03 mm
Range of Motion	S-Axis (turning)	-170° - +170°
	L-Axis (lower arm)	-65° - +145°
	U-Axis (upper arm)	-116° - +255°
	R-Axis (wrist roll)	-190° - +190°
	B-Axis (wrist pitch/yaw)	-135° - +135°
	T-Axis (wrist twist)	-360° - +360°
Maximum Speed	S-Axis	6.54 rad/s, 375° /s
	L-Axis	5.50 rad/s, 315° /s
	U-Axis	7.15 rad/s, 410° /s
	R-Axis	9.59 rad/s, 550° /s
	B-Axis	9.59 rad/s, 550° /s
	T-Axis	17.45 rad/s, 1000° /s
Allowable Moment[4)]	R-Axis	17 N•m (1.73 kgf•m)
	B-Axis	17 N•m (1.73 kgf•m)
	T-Axis	10 N•m (1.02 kgf•m)
Allowable Inertia (GD^2/4)	R-Axis	0.5 kg•m^2
	B-Axis	0.5 kg•m^2
	T-Axis	0.2 kg•m^2
Approx. Mass		34 kg
Protective enclosure		IP67
Mounting method[5)]		Floor-, wall-, tilt-, ceiling-mounted,
Ambient Conditions	Temperature	15 to 45°C
	Humidity	20 to 80% RH (non-condensing)
	Vibration	4.9 m/s² (0.5G) or less
	Altitude	1000 m or less
	Others	Free from corrosive gas or liquid, or explosive gas Free from dust, soot, or water Free from excessive electrical noise (plasma) Free from strong magnetic field
Power Capacity		1 kVA
Applicable controller		YRC1000/YRC1000micro
Noise[6)]		75 dB or less

Mobile Robot

- The main feature of mobile robots is the presence of a mobile base which allows the robot to move freely in the environment.
- From a mechanical viewpoint, a mobile robot consists of one or more rigid bodies equipped with a locomotion system. This description includes the following two main classes of mobile robots:

Wheeled mobile robots typically consist of a rigid body and a system of wheels which provide motion with respect to the ground.	Legged mobile robots are made of multiple rigid bodies, interconnected by prismatic joints or, more often, by revolute joints.

1.2. ROBOT MECHANICAL STRUCTURE

Mobile Robot + Manipulator = Mobile Manipulator

- It is obviously possible to merge the mechanical structure of a manipulator with that of a mobile vehicle by mounting the former on the latter. Such a robot is called a mobile manipulator and combines the dexterity of the articulated arm with the unlimited mobility of the base.

1.3. ROBOT MODELLING, PLANNING AND CONTROL

Modelling

- Kinematic analysis of the mechanical structure of a robot concerns the description of the motion with respect to a fixed reference Cartesian frame by ignoring the forces and moments that cause motion of the structure.
- The formulation of the kinematics relationship allows the study of two key problems of robotics, namely, the direct kinematics problem and the inverse kinematics problem.
- Direct kinematics concerns the determination of a systematic, general method to describe the end-effector motion as a function of the joint motion by means of linear algebra tools.
- Inverse kinematics concerns the inverse problem; its solution is of fundamental importance to transform the desired motion, naturally prescribed to the end-effector in the workspace, into the corresponding joint motion.
- The availability of a manipulator’s kinematic model is also useful to determine the relationship between the forces and torques applied to the joints and the forces and moments applied to the end-effector in static equilibrium configurations.

1.3. ROBOT MODELLING, PLANNING AND CONTROL

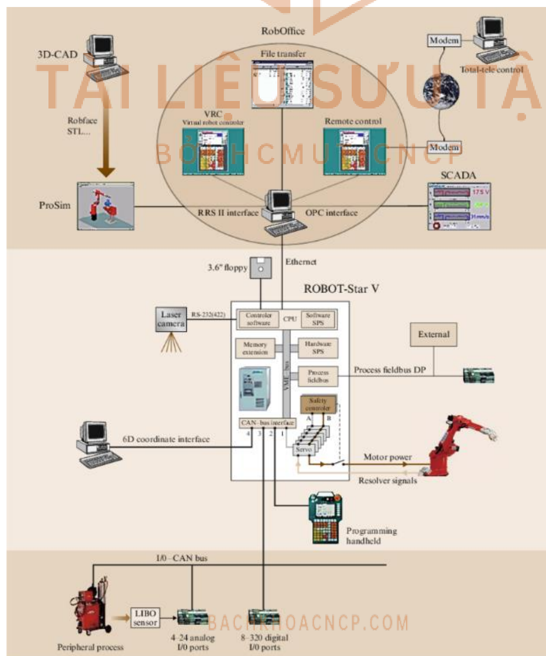
Planning

- In material handling tasks, it is sufficient to assign only the pick-up and release locations of an object (point-to-point motion), whereas, in machining tasks, the end-effector has to follow a desired trajectory (path motion).
- The goal of trajectory planning is to generate the timing laws for the relevant variables (joint or end-effector) starting from a concise description of the desired motion.
- The motion planning problem for a mobile robot concerns the generation of trajectories to take the vehicle from a given initial configuration to a desired final configuration. Such a problem is more complex than that of robot manipulators, since trajectories have to be generated in respect of the kinematic constraints imposed by the wheels.

1.3. ROBOT MODELLING, PLANNING AND CONTROL

Control

- Realization of the motion specified by the control law requires the employment of actuators and sensors.
- The trajectories generated constitute the reference inputs to the motion control system of the mechanical structure. The problem of robot manipulator control is to find the time behaviour of the forces and torques to be delivered by the joint actuators so as to ensure the execution of the reference trajectories.



Appendix: What's next in industrial robotics?

■ Changing nature of manufacturing and work

- ❖ Shift from high volume/low mix to low volume/high mix is having a profound impact on manufacturing.
- ❖ Many industries are facing acute shortages of skilled labor.
- ❖ Quicker return-of-investment (ROI) of automation and rising wages are eventually discouraging labour arbitrage.
- ❖ Increased focus is being placed on workplace safety

Source: Steven Wyatt (IFR). "Today's trends, tomorrow's robots!" Frankfurt, 27 September 2017

Appendix: What’s next in industrial robotics?

Addressing some real facts opens huge opportunities

The Trends	The Challenges	The Enablers
Low volume high mix	Automation complexity and unpredictability	Collaborative automation for greater flexibility
Shorter cycles, faster launches	Shop floor disruptions and high engineering costs	Better software for engineering efficiency
Increased need for automation and scalability in SMEs	Lack of robot integration and programming expertise	Easier to use robots with more intuitive programming
Rising cost of downtime	Higher lifetime TCO due to increase in planned downtime	Advanced analytics and services for greater reliability
Increased and sporadic human intervention	Lost productivity to maintain safety	Collaborative automation to maintain safety and productivity

Appendix: What's next in industrial robotics?

■ Simplification (critical for SME, but also for large global manufacturers)

- Robots easier to install, program (with open source) and operate will unlock entry barriers to the large market of small and medium enterprises (SMEs).
- Trend towards having production closer to the end consumer is driving the importance of standardisation & consistency across global brands.

■ Digitalisation (Big Data allows taking better decisions on factory operations).

- "Industry 4.0", linking the real-life factory with a virtual/digital one, will play an increasingly important role in global manufacturing.
- Vision and sensing devices, coupled with analytics platforms, will pave the way for new industry business models.
- IoT/AI/Machine Learning will drive many robotics developments in coming years.

■ Collaboration

- Collaborative robots are shifting the traditional limits of "what can be automated?".
- Collaborative robots increase manufacturing flexibility as 'low-volume, high-mix' becomes the main standard.
- Collaboration is also about productivity with increased physical and cognitive human/robot interaction